Simultaneous age-metallicity estimates of the Hyades open cluster from three binary systems

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Abstract. Three binary systems in the Hyades open cluster (51 Tau, V818 Tau, and θ^2 Tau), with known metallicity and good Johnson photometric data are used to test the validity of three independent sets of stellar evolutionary tracks. A statistical method is described and applied to the colour-magnitude diagram of the six selected components, giving rise to χ^2-contours in the age-metallicity plane. The effects of the Hipparcos parallaxes on these confidence regions are studied in detail for these binaries through a comparison with very accurate but older orbital parallaxes. Independent simultaneous age-metallicity estimates are given and compared with observational constraints.

1. Introduction

Since the members of an open cluster are assumed to be of same age and chemical composition, these stars are currently used to test the validity of stellar evolution theories, mainly because main sequence stars define a tight sequence in a colour-magnitude diagram (CMD). Unfortunately, this tightness is sometimes misleading because of the contamination by field stars, the presence of unresolved binaries and also the influence of stellar rotation on the location of massive stars in CMDs. Alternatively, well-detached binaries are powerful tests when fundamental parameters are accurately known (see the comprehensive review by Andersen 1991 on double-lined eclipsing binaries). Unfortunately, the determination of their chemical composition often remains a difficult and unresolved issue. It appears therefore that a better test could be performed by combining both advantages, that is, testing the tracks with well-detached double-lined binaries which are members of open clusters. We have applied this idea to three well-detached binaries members of the Hyades: 51 Tau, V818 Tau, and θ^2 Tau.

Observational data : Torres et al., 1997 ([TSL97a], [TSL97b] and [TSL97c]) obtained the first complete visual-spectroscopic solutions for the 3 above-mentionned systems, from which they carefully derived very accurate parallaxes and individual masses. They also gathered some individual photometric data in the Johnson system. Furthermore, we found useful trigonometric parallaxes information in the Hipparcos catalogue (ESA, 1997). By combining the two sources of data, we investigate the influence of the Hipparcos parallaxes on our method which was developed to test stellar evolutionary models in HR diagrams.

Theoretical tracks : Among the most widely used stellar theoretical tracks in the literature are those computed by the Geneva group (see Charbonnel et al. 1993 and references therein) and the Padova group (see Fagotto et al. 1994 and references therein). We also used the stellar tracks from Claret & Giménez (1992) (CG92 thereafter). The tests are done with these 3 series of stellar tracks.

Tests in the CMD : The tests we want to perform are the following :

1. to check whether the two components of the systems are on the same isochrone, i.e. on a line defined by the same age and the same chemical composition for the two single stars.

2. since all the selected stars are members of the Hyades whose metallicity has been well measured (according to the review of Perryman et al. (1998): [Fe/H] = 0.14 $\pm$ 0.05, i.e: Z $=0.024^{+0.0025}_{-0.003}$), we can also check that the predicted metallicities from theoretical models are correct.

3. for 51 Tau and θ^2 Tau, the individual stellar masses are known with an accuracy of about 10%, and for V818 Tau, masses and radii are known with an accuracy close to 1-2%, allowing further tests with the theoretical models.

Therefore, if one of these criteria is not clearly fullfilled by a given set of tracks, then these models have obvious problems since they do not account for several observational constraints (namely the metallicity, mass, radius, and/or the photometric data).

Photometric calibrations : We do not claim that the 6 selected Hyades stars allow us to test without ambiguity any set of theoretical stellar tracks. Since the data are presented in CMD, we are in fact testing not only the validity of the tracks but also of the photometric calibrations, and disentangling the relative influence of both is a tricky task. We use the Basel Stellar Library (BaSeL) photometric calibrations, extensively tested and regularly updated for a larger set of parameters (see Lejeune et al. 1997, 1998 and Lastennet et al. 1999a). For reasons developed in Lastennet et al. (1999b), we assume that the calibrations from the BaSeL models are reliable enough for this work (for more details and

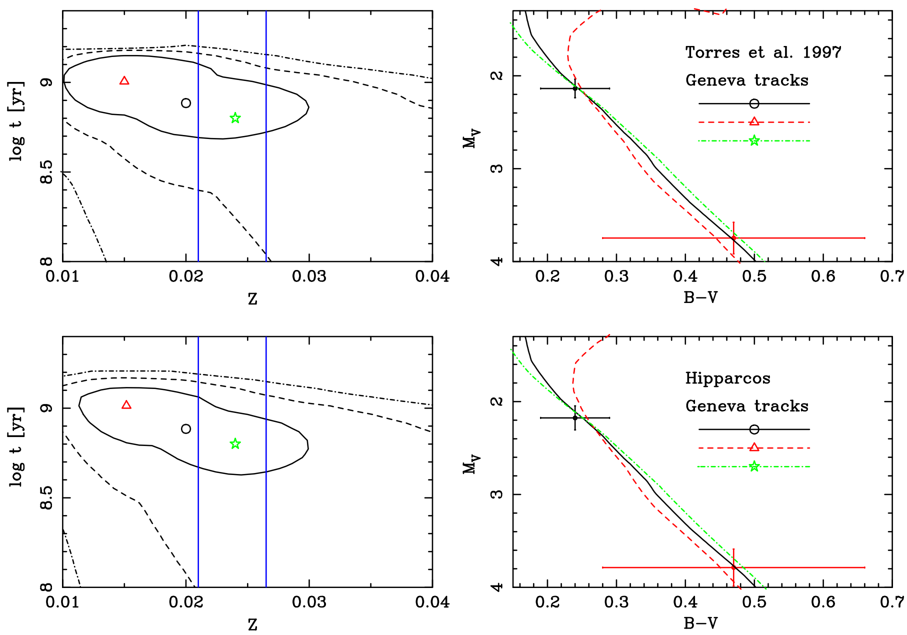

Figure 1. 51 Tau system : influence of the Hipparcos parallax on the contour levels derived from the Geneva tracks. The location of each star in the CMD is from Torres et al. [TSL97a] (in the *bottom panel*, M_V is derived from the Hipparcos parallax). In isocontours plots, the best fits ($\chi^2_{\rm min}$) are marked by *open circles*. The result of Perryman et al. (log t = 8.80, Z = 0.024) is shown for comparison (*star*). The 1, 2, and 3σ contour levels (respectively *solid*, *dashed* and *dot-dashed lines*) are not significantly modified. Vertical lines in contour diagrams show the observational limits for the metallicity of the Hyades.

references on the BaSeL library, see contributions of Lejeune et al. and Westera et al. in this volume).

Brief description of the statistical method : In order to derive simultaneously the metallicity (Z) and the age (t) of the system, and to produce confidence level contours (see Figure 1), we minimize the χ^2-functional defined as:

$$\chi^2(t,Z) \quad = \quad \sum_{i=A}^{B} \left[\left(\frac{\mathrm{M_V(i)_{mod}} - \mathrm{M_V(i)}}{\sigma(\mathrm{M_V(i)})} \right)^2 + \left(\frac{\mathrm{(B-V)(i)_{mod}} - \mathrm{(B-V)(i)}}{\sigma(\mathrm{(B-V)(i)})} \right)^2 \right] \quad (1)$$

where A is the primary and B the secondary component. M_V and (B−V) are the observed values, and $\mathrm{M}_{V\,\rm mod}$ and $\mathrm{(B-V)_{mod}}$ are obtained from the synthetic computations of the BaSeL models using a given set of stellar tracks.

2. Results

Table below briefly summarizes the results (see Lastennet et al. 1999b for further details) of the theoretical simultaneous age–metallicity estimates obtained from isochrone age fitting (1σ level) taking into account the Hipparcos parallax.

System	Geneva		Padova		CG92	
	Z	log t	Z	log t	Z	log t
51 Tau	$0.020^{+0.010}_{-0.008}$	$8.88^{+0.22}_{-0.23}$	$0.017^{+0.021}_{-0.005}$	$8.90^{+0.15}_{-0.55}$	$0.018^{+0.012}_{-0.006}$	$8.92^{+0.23}_{-0.17}$
V818 Tau			$0.033^{+0.017}_{-0.015}$	$7.30^{+2.50}_{-0.30}$		
θ^2 Tau	$0.027^{+0.013}_{-0.010}$	$8.80^{+0.05}_{-0.09}$	$0.027^{+0.023}_{-0.011}$	$8.80^{+0.03}_{-0.11}$	$0.027^{+0.003}_{-0.005}$	$8.88^{+0.02}_{-0.02}$

- For 51 Tau and θ^2 Tau, the 3 sets of isochrones give good fits in the CMD, in agreement with previous estimates (Perryman et al.) of age (log t = $8.80^{+0.02}_{-0.04}$, from isochrone fitting technique with the CESAM stellar evolutionary code (Morel 1997)) and metallicity ([Fe/H] = 0.14 ± 0.05).
- The Geneva and CG92 models can not be tested with the less massive component of V818 Tau. The Padova tracks provide contours in agreement with the Hyades metallicity only when taking into account the Hipparcos parallax. Otherwise, solutions are too old and metal rich.
- Masses predicted by the 3 sets of tracks are in good agreement with the measured individual masses of each system.
- Padova isochrones can not fit the system V818 Tau in a mass-radius diagram.

References

Andersen, J. 1991, ARA&A, 3, 91

Charbonnel, C., Meynet, G., Maeder, A., Schaller, G., Schaerer, D. 1993, A&AS, 101, 415

Claret, A., Giménez, A. 1992, A&AS, 96, 255, [CG92]

ESA, 1997, *The Hipparcos and Tycho Catalogues* (ESA-SP 1200)

Fagotto, F., Bressan, A., Bertelli, G., Chiosi, C. 1994,A&AS, 105, 39

Lastennet, E., Lejeune, Th., Westera, P, Buser, R. 1999a, A&A, 341, 857

Lastennet, E., Valls-Gabaud, D., Lejeune, Th., Oblak, E. 1999b, accepted for A&A, [astro-ph/9905273]

Lejeune, Th., Cuisinier, F., Buser, R. 1997, A&AS, 125, 229

Lejeune, Th., Cuisinier, F., Buser, R. 1998, A&AS, 130, 65

Morel, P. 1997, A&A Suppl., 124, 597

Perryman, M.A.C., Brown, A.G.A., Lebreton, Y., Gómez, A., Turon, C., Cayrel de Strobel, G., Mermilliod, J.-C. 1998, A&A, 331, 81

Torres, G., Stefanik, R.P., Latham, D.W. 1997, ApJ, 474, 256, [TSL97a]
Torres, G., Stefanik, R.P., Latham, D.W. 1997, ApJ, 479, 268, [TSL97b]
Torres, G., Stefanik, R.P., Latham, D.W. 1997, ApJ, 485, 167, [TSL97c]